ISSN 1846-6168
UDK 624.131.53

UTJECAJ KOHEZIJE NA PARAMETRE AKTIVNOG TLAKA HETEROGENOG ANIZOTROPNOG TLA

INFLUENCE OF COHESION ON PARAMETERS OF THE HETEROGENEOUS ANISOTROPIC SOIL ACTIVE PRESSURE

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Original scientific paper

Abstract: *Problems of retaining structures interaction with heterogeneous soil medium assume the anisotropy strength of soil subgrade. Author proposes method of determining of lateral earth pressure considering its anisotropic properties of shear strength. The paper presents numerical study results of subgrades shear strength anisotropy effect on the value of lateral pressure coherent and loose soil along contact with the retaining wall. An analysis of the impact and recommendations on the use of the considered techniques carried out.*

Keywords: *anisotropy of shear strength characteristics, coherent and loose soil medium, lateral earth pressure, heterogeneous subgrade.*

Izvorni znanstveni članak

Sažetak: *Probleme interakcije potpornih konstrukcija sa nehomogenim tlom pretpostavljaju uzimanje u obzir anizotropije čvrstoće podloge od tla. Autor predlaže metodologiju određivanja bočnog tlaka tla s obzirom na njegova anizotropna svojstva čvrstoće na smicanje. U radu su predstavljeni rezultati numeričkog istraživanja utjecaja anizotropije čvrstoće podloge tla na veličinu bočnog tlaka koherentnog i rahlog tla duž kontakta s potpornim zidom. U članku se provodi analiza tog utjecaja i preporuke za implementaciju razmotrene metodologije.*

Ključne riječi: *anizotropija karakteristika čvrstoće na smicanje, koherentno i nekoherentno tlo, bočni tlak, heterogena podloga*

1. INTRODUCTION

Design and operation of retaining structures assume the tasks of determining the lateral earth pressure. The construction of such structures is usually performed in heterogeneous soil medium, which leads to anisotropy of strength characteristics of soil subgrades [1]. Numerous studies made in different countries, confirm the presence of strength anisotropy in natural and artificial subgrades [2-4]. In some cases, the results of direct shear tests confirm difference of soil strength characteristics by several times in different directions. Regulatory documentation does not give clear guidance on considering anisotropic properties of soil subgrades for solving contact problems. Thus, the actual task is to determine the lateral earth pressure considering its shear strength anisotropy.

2. PROBLEM FORMULATION AND ASSUMPTIONS

In view of the mainly use of loose fill in hydraulic engineering specific interest induce elucidation of cohesion influence on the value of anisotropic soil lateral pressure.

Previously suggested the solution for determination of heterogeneous soil lateral pressure on the retaining wall considering anisotropic strength of subgrade [5-6]. Since the findings were based on an approximate C. Coulombs theory, which is more acceptable to the active pressure, let's consider solution that reflect cases of active interaction of anisotropic soil with retaining structures. Calculation scheme is shown on Fig. 1.

Steep rough wall with height H interacts with the two-layer anisotropic medium, which anisotropic strength properties shown by corresponding to each layer hodographs of internal friction angle $\varphi_n(\beta)$ and cohesion $c_n(\beta)$ that fulfill the condition:

$$\varphi_n(\beta) = \varphi_n(\beta + \pi);\ c_n(\beta) = c_n(\beta + \pi) \qquad (1)$$

Soil massif is inclined at an angle $\beta_{1,1}$[1] to the horizontal reference axis. The surface of the second layer is inclined at an angle $\beta_{1,2}$ to the horizontal plane; h_1 and h_2 - thickness of the layers on the vertical projection of the wall. The wall is inclined at an angle β_3 to the reference axis. δ_1 (β_3) and δ_2 (β_3) - angles of wall roughness on contact with the first and second layer respectively.

[1] In this and all subsequent parameters first index indicates number of the parameter, second number of layer.

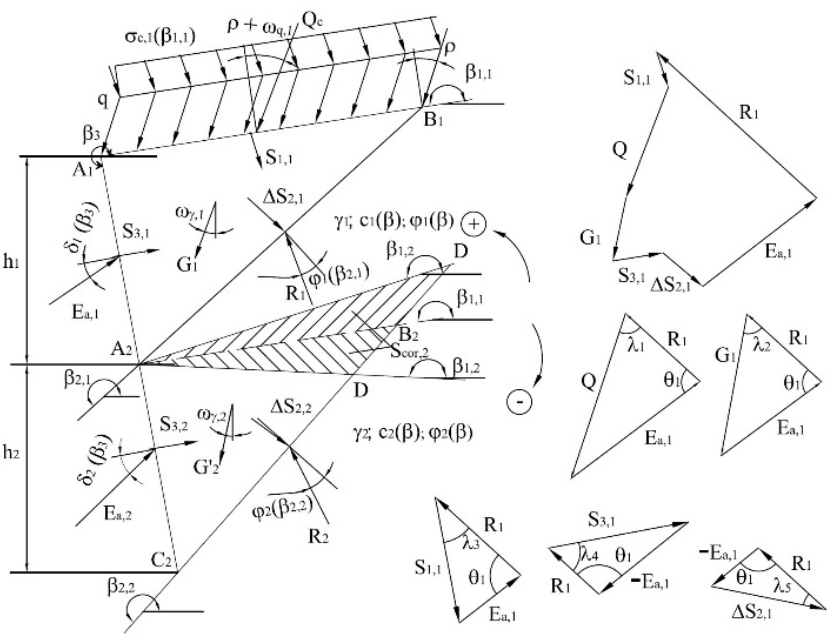

Figure 1 The calculation scheme and force polygons to determine the active pressure of heterogeneous anisotropic soils.

The surface of the massif is uniformly loaded by distributed load of intensity q, which deviated from the normal to the surface of the ground at an angle ρ; $\omega_{\gamma,1}$, $\omega_{\gamma,2}$ - deflection angles from the vertical mass forces during a seismic event, determined in accordance with [7] and [8] in the n-th layer of soil backfill according to the formula:

$$\omega_{\gamma,n} = arctg\left[\left(\qquad \right)/\left(-\frac{\gamma_{nas,n}}{\gamma_{vzv,n}}\alpha sin\chi\right)\right] \tag{2}$$

where $\gamma_{nas,n}$, $\gamma_{vzv,n}$, are the unit weight of n-th layer soil, respectively, in a saturated and buoyant state;

α - coefficient of seismicity, equal to a product of factors, which taking into account the functional responsibility of structures and seismicity of the construction area on the dynamic factor, which depends on the type of soil and the own oscillation period of the system [9];

χ - angle of the seismic forces to the horizon.

Unit weight of water-saturated n-th soil layer is determined in accordance with [7], given by the following formula:

$$\gamma_n = \gamma_{vzv,n}\left(1-\frac{\gamma_{nas,n}}{\gamma_{vzv,n}}\alpha\sin\chi\right)/\cos\omega_{\gamma,n} \tag{3}$$

Relation obtained on the assumption of the limiting equilibrium soil prism, which is reflected in the force polygon.

Consideration of cohesion was made according Kako theorem [10], ie, the forces of cohesion within the soil prism is replaced by the application of uniformly distributed cohesive normal pressure $\sigma_{c,n} = c_n(\beta)\cdot ctg\varphi_n(\beta)$ along the contour of the prism. As the base value of cohesion is taken cohesion that acting on the surface of layer considering corresponding hodograph of layer cohesion. Wherein, considered the rule of signs [11]: the resulting negative forces of cohesion is directed along the normal to sliding surface into the soil prism, and positive - in the opposite direction.

Thus, the active pressure of the lower layer considering it's anisotropy given by:

$$E_{a,2} = \gamma_2 h_2^2 N_{\gamma,2} + q_{2,c} h_2 N_{q,2} + c_2(\beta_{1,2}) h_2 N_{c,2} \tag{4}$$

where are:

$$N_{\gamma,2} = \frac{1}{2}\frac{\sin(\beta_3-\beta_{1,1})\sin(\beta_3-\beta_{2,2})\sin(\varphi_2(\beta_{2,2})-\beta_{2,2}-\omega_{\gamma,2})}{\sin^2\beta_3\sin(\beta_{2,2}-\beta_{1,1})\sin(\beta_3-\beta_{2,2}+\varphi_2(\beta_{2,2})+\delta_2(\beta_3))} \tag{5}$$

$$N_{q,2} = \frac{\sin(\beta_3-\beta_{2,2})\sin(\beta_{1,1}-\beta_{2,2}-\rho_2-\omega_{q,2}+\varphi_2(\beta_{2,2}))}{\sin\beta_3\sin(\beta_{2,2}-\beta_{1,1})\sin(\beta_3-\beta_{2,2}+\varphi_2(\beta_{2,2})+\delta_2(\beta_3))} \tag{6}$$

$$N_{c,2} = \left\{\begin{aligned}&\frac{\sin(\beta_3-\beta_{2,2})\sin(\beta_{1,2}-\beta_{2,2}+\varphi_2(\beta_{2,2}))}{tg\varphi_2(\beta_{1,2})\sin(\beta_{2,2}-\beta_{1,2})}+\frac{c_2(\beta_3)\sin(\beta_3-\beta_{2,2}+\varphi_2(\beta_{2,2}))}{c_2(\beta_{1,2})tg\varphi_2(\beta_3)}+\\&+\left[\frac{c_2(\beta_{2,2})}{c_2(\beta_{1,2})}ctg\varphi_2(\beta_{2,2})-ctg\varphi_2(\beta_{1,2})\right]\frac{\sin(\beta_3-\beta_{1,2})\sin\varphi_2(\beta_{2,2})}{\sin(\beta_{2,2}-\beta_{1,2})}\end{aligned}\right\}\cdot\frac{1}{\sin\beta_3\sin(\delta_2(\beta_3)+\beta_3-\beta_{2,2}+\varphi_2(\beta_{2,2}))} \tag{7}$$

Angle $\beta_{2,2}$ in formulas (5-7) representing the orientation of the surface of the lower layer collapse, unknown and is determined by iteration. Search sliding surface orientation corresponding to the limiting pressure is greatly simplified by the use of computer technology. To do this, on the basis of obtained algorithm was developed a special program to determine the active pressure of an arbitrary anisotropic soil layer, allowing a numerical study of the shear strength anisotropy influence on value of active earth pressure.

In this particular case, vertical perfectly smooth wall that interacts with two layers soil medium was considered. Hodographs of soil strength properties of this two layers was identical and are given in the form of a piecewise linear plots (Fig. 2).

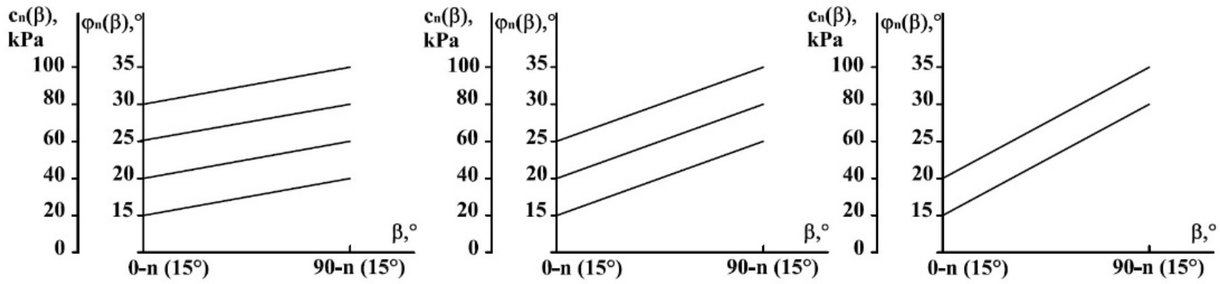

Fig. 2 Piecewise linear hodographs of soil internal friction angle and cohesion taken in the numerical study; n - integer variable

In the calculation orientation of layers are parallel and horizontal, seismic impact and surface load are absent. A wide range of raw data taken into account, allow to trace the influence of the anisotropy in a wide range.

To estimate the effect of shear strength anisotropy on value of heterogeneous soil medium lateral pressure in a numerical experiment was transpired values of active pressure during the rotation of upper and lower soil layer shear strength anisotropy hodograph with the layering orientation of the plane relative to horizontal between 0° and 180° with a step of 15°, as well as the joint hodograph rotation of both layers at an arbitrary angle between the planes of layering.

Calculations were performed for cohesive soils, and also considered calculation without internal forces of cohesion that allowed us to estimate the effect of cohesion on pressure of anisotropic soil.

As a result of the calculation the characteristics of the active pressure was determined:

- Coefficients $N_{\gamma,2}$ and $N_{c,2}$, respectively, characterizing the influence of its own weight and the cohesion of soil medium;
- A component of active pressure of the lower layer $E_{a,2}$;
- Angle of orientation of the sliding surface $\beta_{2,2}$, corresponding to extreme pressure.

To evaluate the effect of anisotropy the anisotropy coefficient of the lower layer was determined:

$$k_{a,2} = \frac{E_{a,2}(anis.)}{E_{a,2}(isotrop.)} \tag{8}$$

where $E_{a,2}$ (anisotropic) are - active earth pressure of the lower layer which is defined considering a shear strength anisotropy; $E_{a,2}$ (isotropic) - active earth pressure of the lower layer wich is defined in terms of an isotropic soil medium at $\varphi_2 = \varphi_{2,min}$= const, $c_2 = c_{2,min}$ =const. The results obtained by research presented in tabular and graphical form.

The following table presents the results of numerical experiment for anisotropic soil at hodograph shear strength anisotropy of cohesive soil φ = 15° - 20° and c = 20 - 40 kPa (Table. 1), as well as for cohesionless soil (Table. 2).

Table 1 Table of parameters $N_{\gamma,2}$, $N_{c,2}$, $E_{a,2}$, $\beta_{2,2}$, $k_{a,x,2}$ depending on the orientation of the plane of layering ϖ relative to the horizontal at given hodographs of internal friction angle and the cohesion of the lower layer φ = 15° – 20°, c = 20 - 40 kPa:

ϖ	$N_{\gamma,2}$	$N_{c,2}$	$E_{a,2}$	$\beta_{2,2}$	$k_{a,x,2}$
0	0,2634284	-4,040729	-67,37972	228	4,296106
15	0,2716106	-2,755244	-50,43688	227	3,215837
30	0,2790588	-1,795409	-33,64556	225	2,145229
45	0,2886751	-1,051567	-16,82459	225	1,072729
60	0,2886751	-0,600767	-5,30313	240	0,338126
75	0,2803978	-0,352402	1,37888	240	-0,087917
90	0,2723510	-0,132416	8,59326	240	-0,547903

Table 2 Table of parameters $N_{\gamma,2}$, $N_{c,2}$, $E_{a,2}$, $\beta_{2,2}$, $k_{a,x,2}$ depending on the orientation of the plane of layering ϖ relative to the horizontal at given hodographs of internal friction angle and the cohesion of the lower layer φ = 15° – 20°, c = 0 kPa:

ϖ	$N_{\gamma,2}$	$N_{c,2}$	$E_{a,2}$	$\beta_{2,2}$	$k_{a,x,2}$
0	0,2646176	-	13,49550	231	0,898927
15	0,2731031	-	13,92826	231	0,927753
30	0,2818077	-	14,37219	230	0,957323
45	0,2907509	-	14,82830	230	0,987704
60	0,2908913	-	14,83545	235	0,988181
75	0,2824331	-	14,40409	236	0,959448
90	0,2741877	-	13,98357	236	0,931438

105	0,2652794	-0,589940	-8,10189	239	0,516574
120	0,2576010	-1,122380	-24,27500	239	1,547765
135	0,2501118	-1,762517	-40,11981	239	2,558024
150	0,2476820	-2,457112	-52,89120	230	3,372323
165	0,2554571	-3,131874	-60,04876	229	3,828687
180	0,2634284	-4,040729	-67,37972	228	4,296106
φ = const =15^0, c = const= 20 kPa:					
52	0,2943705	-1,534840	-15,68390	232	1
φ = const =20^0, c = const= 40 kPa:					
55	0,2451453	-1,400415	-43,51420	235	1

105	0,2661350	-	13,57289	236	0,904082
120	0,2582811	-	13,17234	237	0,877402
135	0,2506580	-	12,78356	237	0,851505
150	0,2483347	-	12,66507	232	0,843613
165	0,2563876	-	13,07576	232	0,870969
180	0,2646176	-	13,49550	231	0,898927
φ = const =15°, c = const= 0 kPa:					
52	0,2943705	-	15,01289	232	1

a) b)

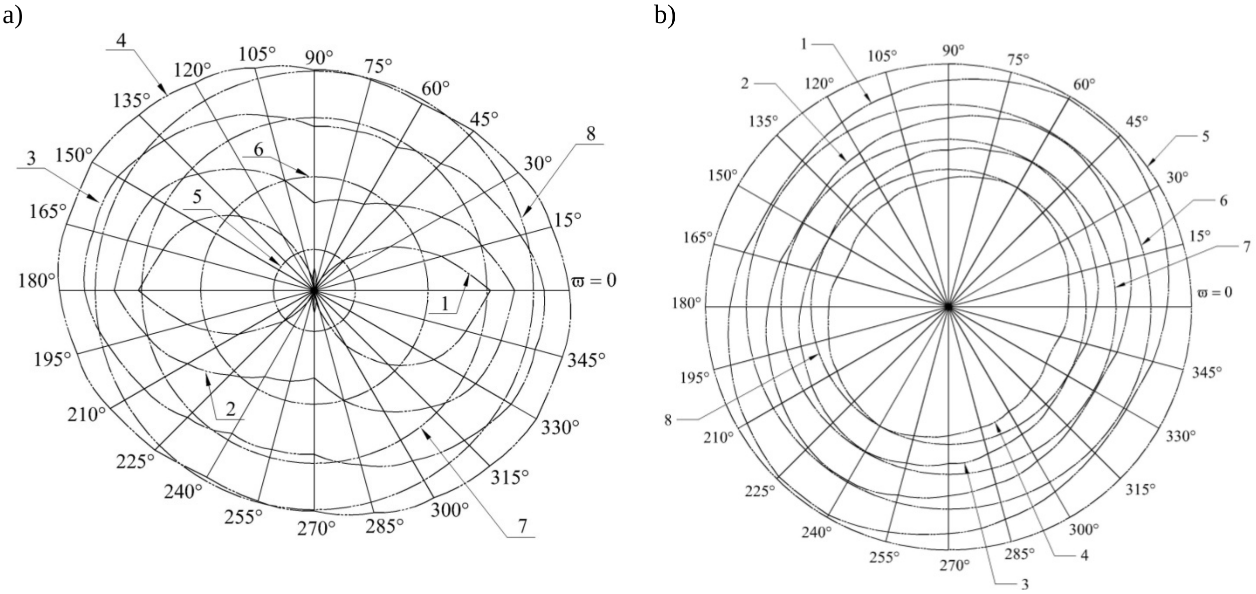

Figure 3 Plots of active pressure dependence $E_{a,2}$ on the orientation of the bottom layers layering plane ϖ for a given hodograph of lower layer internal friction angle and cohesion: 1 - $\varphi = 15^0 - 20^0$; 2 - $\varphi = 20^0 - 25^0$; 3 - $\varphi = 25^0 - 30^0$; 4 - $\varphi = 30^0 - 35^0$; 5 - φ = const = 15^0; 6 - φ = const = 20^0; 7 - φ= const = 25^0; 8 - φ = const = 30^0 a) 1 - c = 20 - 40 kPa; 2 - c = 40 - 60 kPa; 3- c = 60 - 80 kPa; 4 - c = 80 - 100 kPa; 5 - c = const = 20 kPa; 6 - c = = const = 40 kPa; 7 - c = const = 60 kPa; 8 - c = const = 80 kPa; b) c = 0

Fig. 3, a and b shows a graphical relation of lower layer active pressure on the layering plane orientation of the lower layer hodograph, respectively, for a coherent and loose soil.

3. CONCLUSION

Analysis of graphic material leads to the following conclusions:

1. The minimum lateral pressure of coherent soil corresponds to the case when the orientation of the layering plane is horizontal (ϖ = 0), i.e., along the side edge of the wall acts maximum cohesion pressure. Maximum lateral pressure (at $c \neq 0$) corresponds to the vertical orientation of the layering plane, whereby the cohesion pressure that act on side edge of the wall, which take lateral pressure is minimal.
2. Increasing of soil cohesion leads to a reduction of anisotropy coefficient influence.
3. In the absence of cohesion the change of strength properties dose not effect anisotropy coefficient.
4. Graphical relations for active pressure are similar to relations obtained for $N_{c,n}$, and when c = 0 to relation for $N_{\gamma,n}$.
5. Reduction of internal friction angle leads to closure of graphic relation of active pressure and parameter $N_{c,n}$.
6. Coefficient of anisotropy influence significantly depends on the soil cohesion. In the absence of cohesion, the pressure determined considering shear strength anisotropy is always less than the pressure corresponding to an isotropic soil medium, while for coherent soil at a specific hodograph orientation, anisotropy coefficient prevails over the isotropic case. Increasing of subgrade cohesion as strength parameter, resulting in increasing of the parameter $N_{c,n}$, and consequently to reduction of active soil pressure.

Thus, the numerical results show a significant influence of cohesion on the value and character of heterogeneous anisotropic soil pressure, which, of course, must be taken into account in the design, construction and operation of retaining structures.

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